Electromagnetically controlled low-pressure hydraulic valve

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***Abstract*—Basic functions and properties of an electromagnetically controlled low-pressure hydraulic valve are investigated. The construction of the valve is described together with its principal operating regimes. A mathematical model describing its static and dynamic characteristics is proposed. This model is solved numerically by the finite element method. The obtained results are presented and discussed.**

Keywords*—electromagnetically controlled valve; finite element method; force effects; operating regimes.

I. Introduction

An electromagnetic valve is designed for a controlled dosing of low-pressure fluid flowing through it - see Fig. 1. It is adapted to work in two arbitrarily long and recurring operation regimes "open" and "closed". Two short transition regimes, "opening" and "closing", are between them. Each of them takes only a few hundredths of a second.

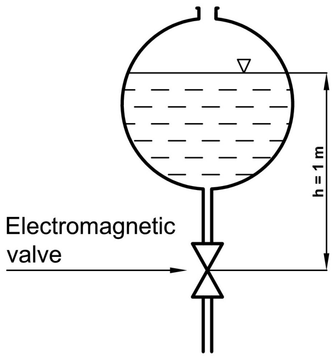

Fig. 1: Schematic arrangement of tank and valve

A. *Formulation of the problem*

The valve has two main parts – a mover and a stationary core. Its arrangement is depicted in Fig. 2.

The mover consists of two ferromagnetic tubes **3** and **4**. These are connected by a hollow non-ferromagnetic (nylon) insert **7**. The element **3** is a conical head of the valve, connected to the stationary core of the valve in the regime "close". This conical head contains six holes with a diameter of four millimeters, which are used for fluid flow in the regime "open". Then the fluid flows into the cavity of the valve through a nylon outlet pipe **10**.

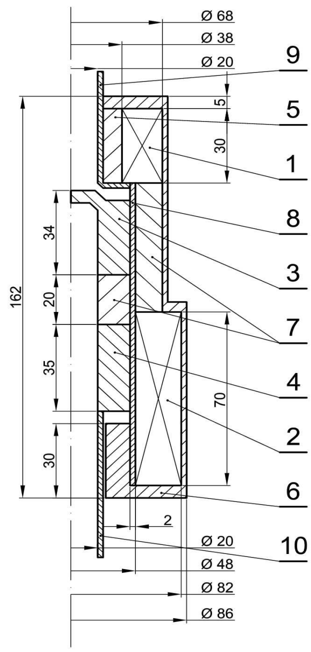

Fig.2: Arrangement of considered valve

The stationary core of the valve consists of a ferromagnetic casing **6** containing a toroid permanent magnet (NEOREC53B [1]) **5** and two coils **1** and **2**. The coils are connected by a non-ferromagnetic (nylon) insert **7** and a nonmagnetic steel tube **8**, which also serves as a guide track for the mover.

B. *Valve operating modes*

A current of density $\boldsymbol{J}_1$ flowing through the coil **1** in the transient mode "opening" (which ends in the stationary regime "open"), produces demagnetization and reduces the impact force of magnet **5** on the ferromagnetic element **3**. At the same time, a current of density $\boldsymbol{J}_2$ flows through the coil **2**. This makes the ferromagnetic element **4** pull into that coil.

An opposite current of density $-\boldsymbol{J}_1$ flowing through the coil **1** in the transient regime "closing" (which ends in the stationary regime "close"), enlarges the impact force of magnet **5** on the ferromagnetic element **3**. The current density $\boldsymbol{J}_2$ is now equal to zero.

II. MATHEMATICAL MODEL AND NUMERICAL SOLUTION

The mathematical model of magnetic field in the whole valve is generally described by the differential equation [2], [3]

$$\mathrm{curl}\left(\frac{1}{\mu}\left(\mathrm{curl}\,\boldsymbol{A}\right) - \boldsymbol{H}_{\mathrm{c}}\right) = \boldsymbol{J}\,. \tag{1}$$

The corresponding vector of the electromagnetic force $\boldsymbol{F}_{\mathrm{m}}$ acting on the mover (in fact, on its ferromagnetic elements **3** and **4**) is given by the integral

$$\boldsymbol{F}_{\mathrm{m}} = \frac{1}{2}\oint_{S}\left[\boldsymbol{H}(\mathbf{n}\boldsymbol{B}) + \boldsymbol{B}(\mathbf{n}\boldsymbol{H}) - \mathbf{n}(\boldsymbol{H}\boldsymbol{B})\right]\mathrm{d}S \tag{2}$$

The solution of (1) and evaluation of the integral (2) was carried out using the codes QuickField and Agros2D. The numerical convergence of the solution was evaluated by calculation – for reaching the accuracy of 3 significant digits it was necessary to use a very fine mesh containing 283 471 triangular elements.

III. RESULTS AND THEIR DISCUSSION

A. Static characteristic

The static characteristic is described by the differential equation (1) and formula (2). Their numerical solutions for different positions of the mover within the interval $z \in \langle 3, 12\rangle$ mm with ferromagnetic elements **3** and **4** located against the stationary core of the valve (see Fig. 1) provided the distribution of the static forces $F_{\mathrm{m}3,4}$ in the regimes

- "opening", $J_1 = +1.5\times10^7$ A/m^2, $J_2 = 3\times10^6$ A/m^2,
- "closing", $J_1 = -1.5\times10^7$ A/m^2, $J_2 = 0$.

The results are depicted in Fig. 3.

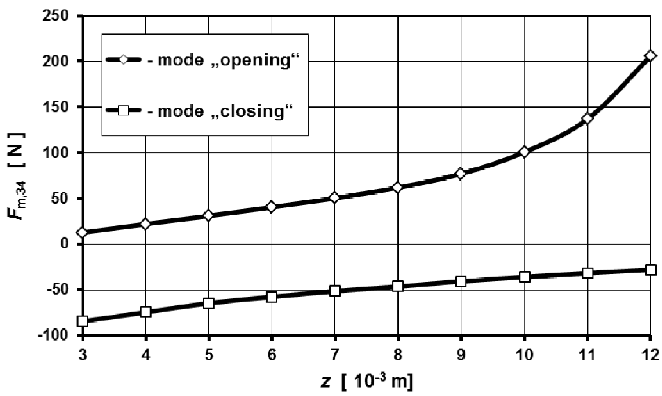

Fig.3: Static characteristic for modes "opening" and "closing"

The time intervals Δt_{op} and Δt_{cl}, for which the regimes "opening" and "closing" run and for which, therefore, current density $J_1 = \pm1.5\times10^7$ A/m^2 must be applied in the coil **1**, are determined from the following dynamic characteristics of the valve.

B. Dynamic characteristic

The dynamic characteristics in this case are described by the differential equations

$$m\frac{\mathrm{d}v}{\mathrm{d}t} = F_{\mathrm{m},34} + F_{\mathrm{G}} + F_{\mathrm{H}}\ , \tag{3}$$

$$\frac{\mathrm{d}z}{\mathrm{d}t} = v\ , \tag{4}$$

where m is the weight of the mover. The symbols v and z are the instantaneous values of the speed and position of the mover, $F_{\mathrm{m},34}$ is the electromagnetic force acting on the mover, F_{G} is the weight of the mover (in our case $F_{\mathrm{G}} = 6.209$ N) and F_{H} stands for the hydrostatic force acting on the closing cone **3**, which is connected with the mover. In our case $F_{\mathrm{H}} = 9.708$ N (determined for H_2O, whose column is 1 m high, see Fig. 1)

The dynamic characteristics of the operating regimes "opening" and "closing" provided the time intervals $\Delta t_{\mathrm{op}} = 0.0167$ s and $\Delta t_{\mathrm{cl}} = 0.0258$ s, for which the regimes "opening" and "closing" run and for which, therefore, current density $J_1 = \pm1.5\times10^7$ A/m^2 in the coil **1** must be applied. Fig. 4 shows the dynamic characteristic for the regime "opening".

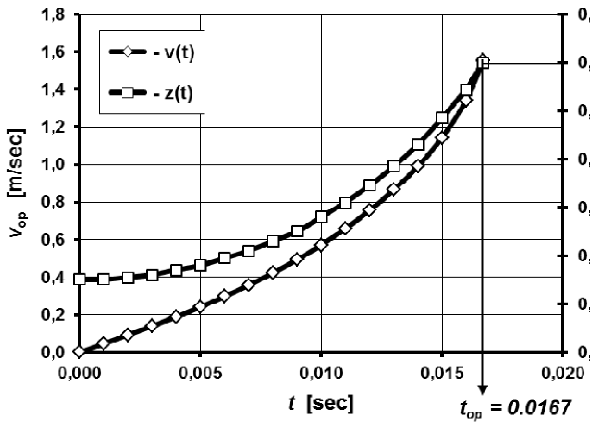

Fig.4: Dynamic characteristic for mode "opening"

IV. CONCLUSION

The results obtained from the numerical solution can be used for design of a real prototype of the electromagnetically controlled low pressure hydraulic valve.

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